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Reply to "Roles of SNIa and SNII in ICM Enrichment" by Y. Ishimaru and N. Arimoto

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Abstract

We address a number of misunderstandings and misstatements contained in the paper "Roles of SNIa and SNII in ICM Enrichment" by Y. Ishimaru and N. Arimoto with regard to the papers by Mushotzky et al. (1996, ApJ, 466, 686) and Loewenstein and Mushotzky (1996, ApJ, 466, 695). In particular, we emphasize that comparison between observations and models in these papers were made self-consistently assuming a particular (*i.e.*, photospheric) value for the solar iron abundance. We also briefly revisit the question of the contribution of Type Ia supernovae to the iron enrichment of the intracluster medium.

Key words: Clusters of galaxies: intracluster medium – Clusters of galaxies: X-rays – Galaxies: intergalactic medium – Galaxies: abundances

1. Introduction

The origin of heavy elements in the intracluster medium (ICM) is an important area of astrophysical research, with implications for the understanding of galaxy and cluster formation, structure, and evolution. We were principle authors on a pair of papers (Mushotzky et al. 1996, Loewenstein and Mushotzky 1996) addressing this issue using *ASCA* data of four clusters of galaxies.

The first paper (Mushotzky et al. 1996) presented the results of the analysis of *ASCA* spectra, noted the superficial resemblance of the abundance pattern to that calculated for Type II supernovae (SNII), and briefly commented on the large number of SNII required to account for these observations and the resulting implications for our understanding of primordial star formation in proto-elliptical galaxies.

The second paper (Loewenstein and Mushotzky 1996) presented a more detailed comparison of the observed elemental mass-to-light ratios and abundance ratios with models of enrichment from SNII explosions of stars with masses distributed according to power-law initial mass functions (IMFs) of various slope. Mass-to-light ratios for Fe, Si, O, etc. were derived by integrating nucleosynthetic yields calculated by Woosley & Weaver (1995) over the IMF, assuming that the present-day light is emitted by stars from the same IMF that produced the SNII, and ignoring Type Ia supernovae (SNIa). We found that a flat IMF was required to reproduce the observed mass-to-light ratios, and that the results were consistent for Fe, Si, and O. Since O is exclusively, and Si predominantly, synthesized by SNII there is no need to invoke significant enrichment by SNIa. It, of course, does *not* follow that the importance of SNIa in accounting for the Fe enrichment can be ruled out, and we did not do so (see below).

We also compared observed ratios of abundances relative to Fe with abundance ratios in the models. This comparison was made in an internally consistent way by forming the ratios of the model mass-to-light ratios and then *normalizing them to the same abundances taken to be solar in the spectral analysis.* Because of uncertainties in the measured abundances and in the nucleosynthetic Fe yields, we did not draw strong conclusions about the IMF from this comparison.

An additional unknown that plays off against the Fe yield uncertainty in explaining abundance ratios relative to Fe, is the contribution of SNIa to the Fe enrichment. As stated in Section 7.2 of Loewenstein & Mushotzky (1996), more than one-third of the Fe could originate from SNIa if the standard Woosley & Weaver (1995) Fe yield is assumed; moreover, this fraction can climb to 75% or more if the yield uncertainty is explicitly considered. The ambiguity in interpreting the observed Fe abundances has little effect on our conclusions about the number of SNII required to explain the observations since large O, Ne, and Si abundances are also observed.

2. Discussion

In the paper by Ishimaru & Arimoto (1997) it is implied that we were inconsistent in using photospheric

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abundances in data analysis while referring to models that assumed meteoritic abundances, and that we ruled out the possibility of significant ICM Fe enrichment by SNIa. As should be clear from the above discussion, neither of these is the case.

First and foremost, our primary conclusions are based on a comparison of observed elemental mass-to-light ratios with those predicted by the models – the assumed solar abundances nowhere enter into calculation of the latter. Secondly, as explained above, we normalized all abundance ratios to the photospheric values – even if the meteoritic abundances are correct, as long as consistency is maintained the comparison is valid. We found that a bimodal star formation model with an IMF slope of ~ 1.5 could explain the observed ratios, but noted that this depended on the uncertain assumptions that SNIa were negligible and that nucleosynthetic yields of Fe are precisely known. Timmes, Woosley, & Weaver (1995) have noted that the latter may be uncertain by a factor of two.

As repeatedly stated in Loewenstein & Mushotzky (1996), the observed abundance ratios neither require nor rule out an important SNIa contribution to the Fe enrichment of the ICM. We have revisited this question in more detail for the clusters AWM 7 and Abell 1060, deriving best simultaneous fits of the total numbers of SNIa and SNII to the observed abundance pattern of Fe, O, and Si. Yields for SNIa are taken from Model W7 of Nomoto et al. (1984), and SNII yields either from Woosley & Weaver (1995; model WW-1 in Loewenstein & Mushotzky 1996), or Thielemann, Nomoto, & Hashimoto (1996). SNII yields are averaged over a Salpeter IMF with an upper limit of $40\mathrm{M}_{\odot}$. We note that the Woosley & Weaver (1995) yields include unprocessed ejecta as well as newly synthesized SNII products. The best-fit values of the mass fractions in the ICM from SNIa are displayed in Tables 1 and 2 for Fe, Si, O, and for the sum of all observed elements (O, Ne, Mg, Si, S, Ar, Ca, and Fe). Upper and lower limits are crudely and conservatively estimated by allowing the abundances to independently vary within their 90% confidence limits. It is clear that there is a large dependence on which set of SNII yields are adopted: the Woosley & Weaver (1995) models favor a modest SNIa contribution to the Fe and negligible contribution to the Si enrichment while not ruling out pure SNII enrichment; the Thielemann et al. (1996) yields (as discussed by Ishimaru & Arimoto 1997) favor a dominant contribution to the Fe and significant contribution to the Si enrichment from SNIa while ruling out pure SNII enrichment.

3. Conclusions

The photospheric abundances adopted in the spectral analysis of intracluster gas in four clusters by Mushotzky et al. (1996) were either irrelevant or self-consistently accounted for in their conclusions and those in Loewenstein & Mushotzky (1996). Because of measurement error and uncertainties in the nucleosynthetic yields of heavy elements by SNII (and the ironic fact that the best measured element, iron, has the most poorly understood yield) relative abundances of intracluster metals as measured by *ASCA* do not, by themselves, significantly constrain the IMF of the SNII progenitors or the relative contributions of SNIa and SNII to the enrichment of iron. As pointed out by Loewenstein & Mushotzky (1996) and again in this work, and emphasized by Ishimaru & Arimoto (1997), SNIa may account for 50% or more of the Fe enrichment. However, any conclusions about the SNIa contribution are highly dependent on assumptions about nucleosynthetic yields (Gibson, Loewenstein, & Mushotzky, in preparation), and much smaller values are allowed. It is clear that virtually all of the observed O, and most of the observed Si do originate from SNII, and that these number greatly in excess of what can be produced by a simple stellar population with a standard IMF (Loewenstein & Mushotzky 1996).

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Table 1. Mass Fractions from SNIa*.

Cluster	iron	silicon	oxygen	total
Abell 1060	$0.23(< 0.74)$	$0.064(< 0.40)$	$0.005(< 0.045)$	$0.028(< 0.22)$
AWM 7	$0.22(< 0.73)$	$0.062(< 0.39)$	$0.005(< 0.044)$	$0.027(< 0.21)$

*Woosley & Weaver (1995) SNII yields are assumed.

Table 2. Mass Fractions from SNIa*.

Cluster	iron	silicon	oxygen	total
Abell 1060	0.68(0.39-0.92)	0.32(0.12-0.71)	0.017(0.005-0.082)	0.096(0.030-0.35)
AWM 7	0.64(0.27-0.90)	0.20(0.048-0.56)	0.014(0.003-0.072)	0.081(0.018-0.32)

*Theilemann et al. (1996) SNII yields are assumed.